



Comanche Station, Pueblo County, Colorado

Monitoring Well Installation Report

Comanche Station

Xcel Energy

August 1, 2016

Rev. 1 June 14, 2018

Rev 2 June 28, 2021

Table of Contents

1.0	Introduction	1
2.0	Background Information	1
3.0	Field and Laboratory Methods.....	5
3.1	Borehole Drilling.....	5
3.2	Soil Samples - Geotechnical Analysis	5
3.3	Well Construction	6
3.4	Well Development	7
3.5	Well Survey	7
3.6	Groundwater Level Measurement and Aquifer (Slug) Testing.....	7
3.7	Decontamination of Field Equipment	9
4.0	Field and Laboratory Results	9
4.1	Borehole Drilling	9
4.2	Soil Samples – Geotechnical Analysis	10
4.3	Well Construction	11
4.4	Well Development	14
4.5	Well Survey	14
4.6	Groundwater Level Measurement and Aquifer (Slug) Testing.....	14
4.6.1	Results	15
5.0	References.....	18

List of Tables

Table 1. Summary of Geotechnical Testing Results at Comanche Station, 2015	10
Table 2. Summary of Geotechnical Testing Results at Comanche Station, 2020	10
Table 3. Well Construction Details for Installed Groundwater Monitoring Wells.....	12
Table 4. Slug Testing Results	16
Table 5. Hydraulic conductivity by lithologic unit	17

List of Figures

Figure 1. Vicinity Map for Comanche Station	3
Figure 2. Well Location Map, Comanche Station	4



List of Appendices

- A. Borehole Logs
- B. Geotechnical Analysis Chain of Custody and Laboratory Reports
- C. Well Construction Diagrams
- D. State-Issued Well Construction Permits
- E. Slug Test Analyses

Table of Abbreviations and Acronyms

AMSL	above mean sea level
bgs	below ground surface
BTOC	below top of casing
CCR	Coal Combustion Residuals
cm/sec	centimeter per second
HP Geotech	Hepworth-Pawlak Geotechnical, Inc.
$\mu\text{S/cm}$	microsiemens per centimeter
NTU	nephelometric turbidity unit
PSCo	Public Service Company of Colorado
SSD	Site Services Drilling, LLC
TOC	top of casing
USCS	Unified Soil Classification System

1.0 Introduction

The purpose of this Monitoring Well Installation Report is to document details pertaining to the drilling, construction, and development of three monitoring wells installed in 2015, two monitoring wells installed in 2017, and 15 groundwater monitoring wells installed in 2020 at the Xcel Energy Comanche Generating Station (Comanche Station) in Pueblo, Colorado (**Figure 1**). The groundwater monitoring system is intended to support compliance with the U.S. Environmental Protection Agency's final Coal Combustion Residuals (CCR) Rule (40 CFR Parts 257 and 261). Comanche Station has two CCR units¹, an impoundment and a landfill, subject to the CCR Rule. The drilling and well installations were performed in accordance with the State of Colorado Water Well Construction Rules (2 Code of Colorado Regulations 402-2).

HDR was contracted to locate, permit, and oversee the installation of the groundwater monitoring wells (installed 2015 and later) at Comanche Station. HDR retained Hepworth-Pawlak Geotechnical, Inc. (HP Geotech) in 2015, Site Services Drilling, LLC (SSD) in 2017, and Dakota Drilling, LLC in 2020 to provide on-site drilling services, while HDR provided field monitoring of the drilling, well installation, and development. All on-site personnel completed the site-specific safety training. Additionally, daily safety briefs were conducted by the on-site project team prior to commencing work. The training and safety briefs were documented in accordance with the *PSCo CCR Rule Compliance Health & Safety Plan*.

2.0 Background Information

Prior hydrogeologic and geotechnical investigations conducted at Comanche Station are identified and summarized in the Comanche Station Monitoring Well Installation Plan (HDR, 2015a). Comanche Station is underlain by unconsolidated colluvium consisting of stiff clays and silts, with interbedded sand and gravel west and south of the CCR landfill. Typical colluvium thickness is approximately 20 feet but ranges between 5 and 75 feet (Woodward-Clyde, 1987; URS, 2005). The Pierre Shale bedrock is below the colluvium and is approximately 1,450 feet thick. The southern and western portions of the substation have thin alluvial sands and gravels above the shale bedrock.

The uppermost known aquifer in literature beneath the Site is the Dakota Sandstone at a depth of over 1,450 feet (GeoTrans, Inc., 2009). Approximately 1,450 feet of low-permeability shale deposits separate the CCR units from this known aquifer. Tetra Tech (2015) estimated the groundwater velocity through the Pierre Shale and estimated that it will take 14,500 years to migrate through the bedrock shale deposits before leachate from the Comanche CCR units would reach the Dakota Sandstone Aquifer.

The monitoring well network prior to the 2020 drilling was established to monitor the colluvium, with screened intervals in the colluvium and well bottoms at the colluvium/shale contact. The wells were placed around the CCR units to capture any groundwater flow around the units, and to determine if a groundwater flow direction could be monitored and observed. Consistent with prior studies, the shallow unconsolidated colluvium deposits beneath the site were observed by HDR between 2015

¹ Comanche Station includes three coal-fired generation units. All CCR generated at Comanche Station is stored in two active CCR units subject to compliance with the CCR Rule: a CCR impoundment and a CCR landfill (Figure 2). The CCR impoundment is located southeast of the coal storage area, and the CCR landfill is west of the raw water storage pond.

and 2020 to be predominantly dry, with some isolated areas of perched water² (GeoTrans, Inc., 2009). Areas of perched water may be controlled by the bedrock topography where water becomes trapped by topographic lows in the shale bedrock surface (GeoTrans, Inc., 2009). A potential south-southeasterly flow gradient was assumed based on the ground surface topography, which slopes to the south-southeast towards the St. Charles River. The alluvial aquifers associated with the Arkansas River (north), the St. Charles River (south), and Salt Creek (west) do not fully extend beneath the site; however boreholes at the south and west edges of the property appear to have alluvial units interbedded with the colluvium, above the shale bedrock.

Three monitoring wells installed in 2015 (W-4, W-5, and W-6) were sited around the Bottom Ash Pond based on monitoring requirements in the CCR Rule, facility design, and existing hydrogeologic data for the vicinity, as described in the Groundwater Monitoring System Certification (HDR, 2020). Well locations are shown on **Figure 2**. These wells were screened in the colluvium to be consistent with the CCR Rule to monitor the uppermost groundwater. The uppermost groundwater known at the site in 2015 was that observed as perched water in the colluvium at W-3 adjacent to the Bottom Ash Pond and MW-3 adjacent to the landfill.

Wells MW-5 and MW-6 were installed in 2017 to provide coverage for the lateral expansion of the landfill. These wells were screened in the colluvium to be consistent with the existing wells surrounding the landfill, and to be consistent with the CCR Rule to monitor the uppermost groundwater (the uppermost groundwater known at the site in 2015-2017 was that observed as perched water in the colluvium at W-3 and MW-3).

As part of additional site hydrogeologic characterization work implemented in 2020 to support an alternate liner demonstration under the EPA CCR Part B Final Rule (November 12, 2020) (40 CFR 257.71(d)), additional drilling was performed into the bedrock that resulted in fifteen (15) new (deeper) monitoring wells at the site in August 2020 and December 2020. Eight of the new monitoring wells (MW-1B, MW-2B, MW-4B, W-2A, W-2B, W-7, W-8A, W-8B) were installed in August. In December, seven more monitoring wells were installed (W-5B, W-9, W-10A, W-10B, W-11, W-12, and W-13). Five of the wells were screened deeper in the saturated weathered shale bedrock as the uppermost saturated unit to monitor locations where existing colluvial wells have historically been dry (MW-1B, MW-2B, MW-4B, W-2A, W-5B). Ten of the wells were sited to further characterize the complex groundwater system, confirm dry colluvium, and evaluate groundwater at the property boundary (W-2B, W-7, W-8A, W-8B, W-9, W-10A, W-10B, W-11, W-12, and W-13), seven of which (W-7, W-8A, W-9, W-10B, W-11, W-12, and W-13) were screened in the saturated weathered shale as the uppermost saturated unit. One well was screened in the dry colluvium (W-10A), and two wells (W-2B and W-8B) were screened deep in the unfractured, consolidated shale bedrock. Well locations are shown on **Figure 2**.

² Only two of the seven previously installed wells at the site, MW-3 and W-3, have contained measurable water, and most borings previously drilled at the site, including boreholes that penetrate the Pierre Shale, have been dry.

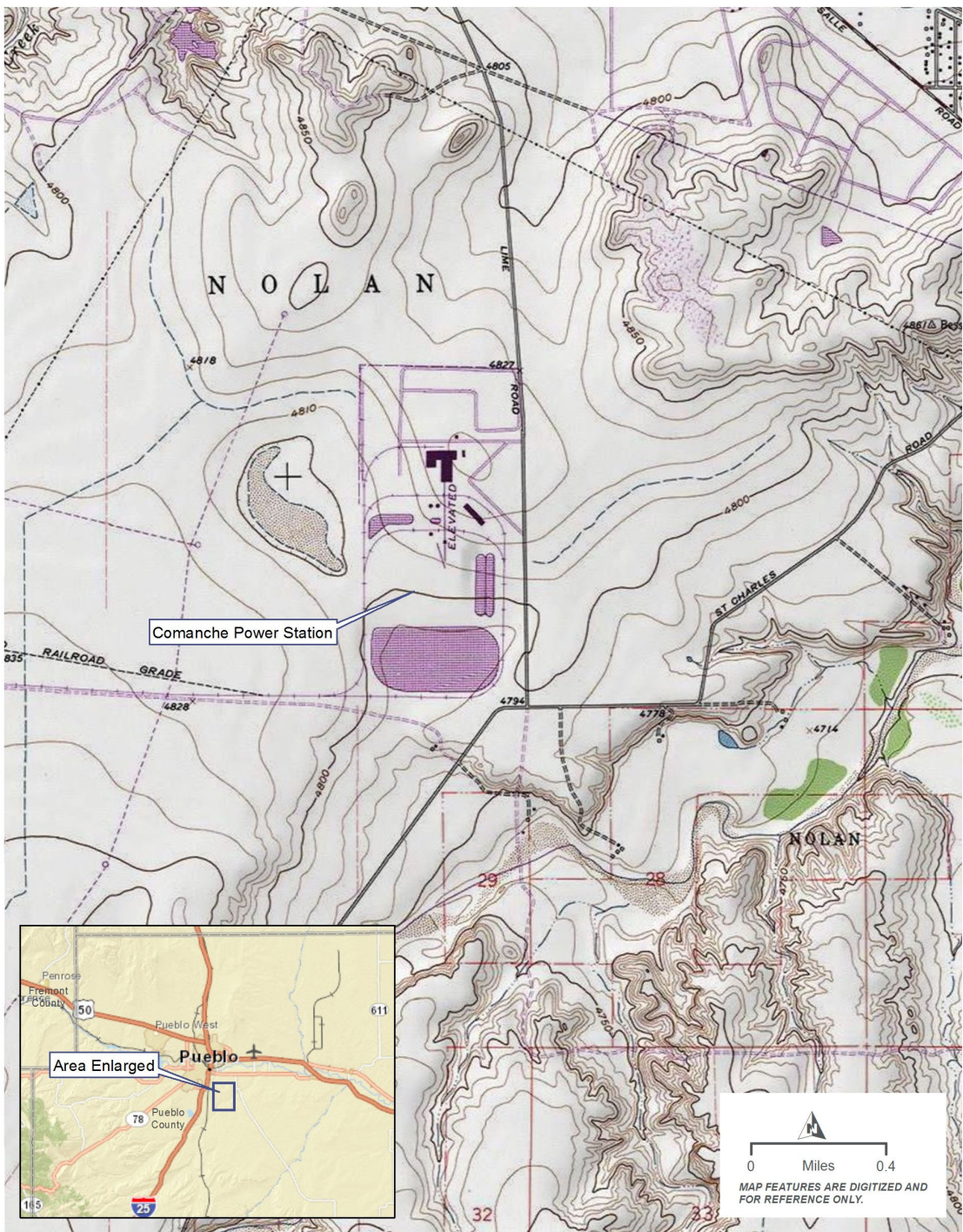


Figure 1. Vicinity Map for Comanche Station

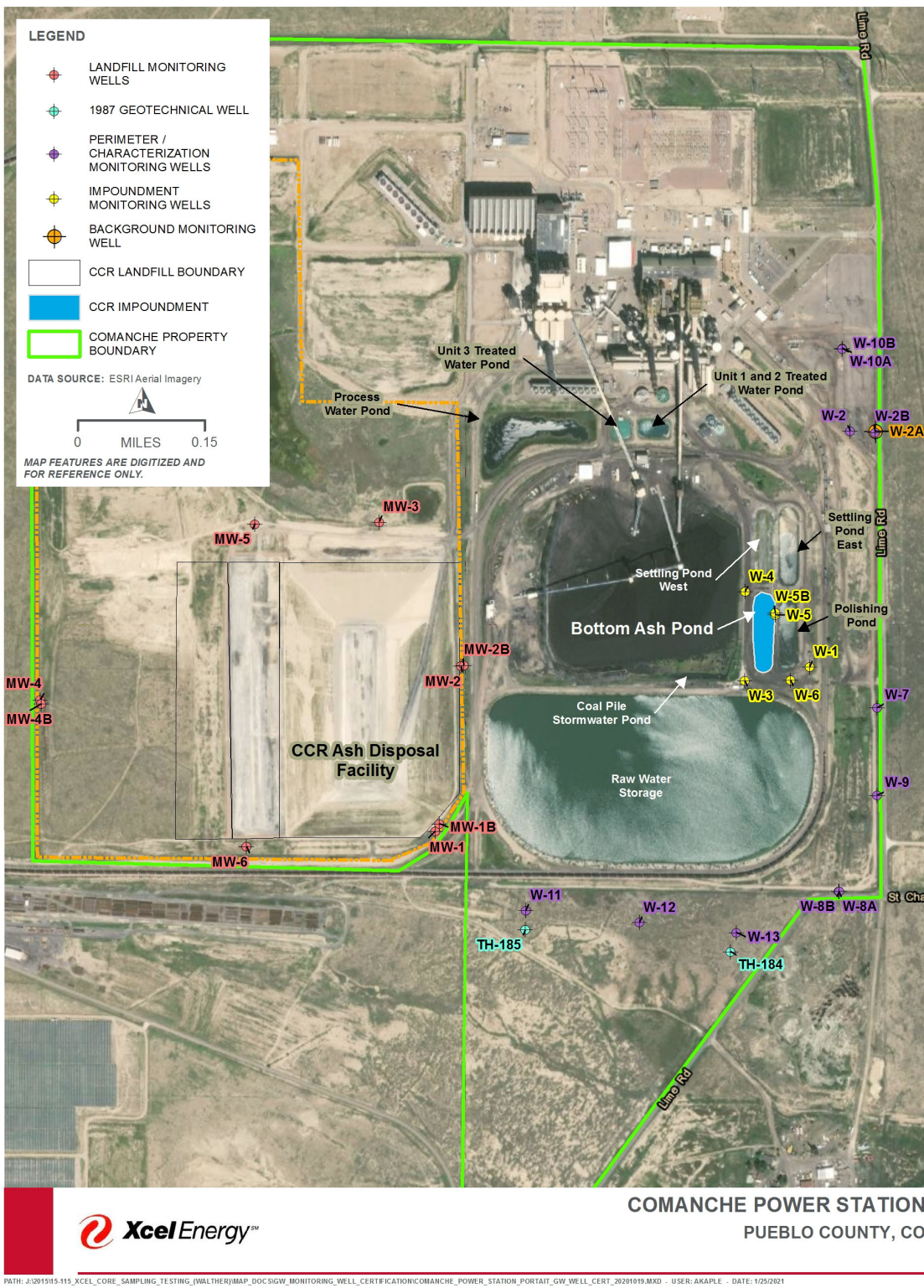


Figure 2. Well Location Map, Comanche Station

3.0 Field and Laboratory Methods

3.1 Borehole Drilling

The boreholes for wells W-4, W-5, and W-6 were drilled by HP Geotech using a hollow stem auger drilling method from November 9 through 11, 2015. The boreholes for MW-5 and MW-6 were drilled by Site Services Drilling (SSD) using the same method from August 7 through 8, 2017. The boreholes for wells MW-1B, MW-2B, MW-4B, W-2A, W-2B, W-7, W-8A, and W-8B in August 2020, and wells W-5B, W-9, W-10A, W-10B, W-11, W-12, and W-13 in December 2020 were drilled by Dakota Drilling using hollow stem auger through colluvium, then coring through bedrock. Once the well depth was determined, the borehole was reamed utilizing air rotary before installation of the monitoring well. Utility locations were identified prior to beginning drilling operations.

Screens for wells installed in 2015 and 2017 were targeted for the uppermost water-bearing zone, if encountered, or above the colluvium-bedrock contact where the hollow stem auger hit refusal. This resulted in total borehole depths that ranged from 25 feet to 75 feet, as further described in **Section 4.3**.

Screens for most wells installed in 2020 were targeting the uppermost groundwater, regardless of lithology, and were installed specifically to evaluate whether groundwater was present in the deeper weathered shale. In addition, wells W-2B and W-8B were screened in the consolidated, unfractured shale, and W-10A was screened above the colluvium-bedrock contact. An HDR geologist was present during core drilling operations to collect samples and log the subsurface material, in addition to overseeing site safety and proper well construction. Soil samples from boreholes were collected in plastic bags and logged every 5 feet by the field geologist during drilling to document lithologic soil characteristics. The geologist visually classified soil type, consistency/relative density, color, and water content in accordance with the Unified Soil Classification System (USCS) as well as grain size, mineralogy, sorting, rounding, hardness, and matrix/clast support, among other textural properties. Where coring was completed, fracture density was also noted. Samples were placed in sample bags labeled with the borehole identification and depth interval. One undisturbed soil sample from each well was collected within the well screen depth interval and submitted to a lab for hydraulic properties analysis, as described in **Section 3.2**. Soil samples were not collected in 2017. Boring logs for each borehole are provided in **Appendix A**.

Soil cuttings, fluids, and potholing slurry generated during drilling were transported to and disposed of at the existing onsite ash landfill. Drilling equipment was decontaminated with potable water before moving to the next borehole.

3.2 Soil Samples - Geotechnical Analysis

Soils were logged from the cutting returns during drilling wells W-4, W-5, and W-6 in 2015 and MW-1B, MW-2B, MW-4B, W-2B, W-7, and W-8A in August 2020 and classified based on the USCS. During drilling, one undisturbed soil sample was obtained from each borehole at a depth coinciding with the well screen depth. An 18-inch long California Modified Style Split-Spoon Sampler was used to collect the undisturbed core of sediment. The undisturbed soil samples (one from each well) were submitted to HP Geotech for analysis of the following parameters in 2015:

- Grain-size: Sieve and Hydrometer (ASTM D421/422)

- Total Porosity (SW9100)
- Bulk Density (ASTM D2937)
- Moisture Content (ASTM D2216)
- Specific Gravity (ASTM D854)

Analysis was completed in accordance with the method for grain-size analysis using sieve and hydrometer described in ASTM D421/422 (ASTM D421-85, 1998 and ASTM D422-63, 2007).

Undisturbed samples collected during drilling in August 2020 were submitted to Advanced Terra Testing (ATT) for the following analyses:

- Moisture Content (ASTM D2216)
- Permeability (ASTM D5084)

Chain of custody documentation and laboratory results are provided in **Appendix B**. Samples were not submitted to the laboratory from MW-5, MW-6, W-2A, or W-8B boreholes due to similarity of materials.

3.3 Well Construction

Once the target drilling depth was reached at each location, the 2-inch diameter, Schedule 40 PVC casing and well screen (0.010-inch slots) were assembled and lowered into the borehole.

Approximately 10 feet of screen was installed in each well screened in the colluvium. To capture infiltrating perched water, a 10-foot long sump consisting of blank casing was placed beneath the screen for colluvial wells³, as requested by CDPHE in a meeting with Xcel Energy on April 24, 2014 (Tetra Tech, 2014). However, a 5-foot long sump was placed beneath the well screen of MW-6 due to drilling refusal.

Wells installed in August 2020 have either 10, 15 or 20 feet of screen depending on the thickness of the weathered shale or to capture a longer section of bedrock for fracture flow. Wells installed in December 2020 have either 5 or 10 feet of screen depending on the thickness of the weathered shale. The well screens are completed just above the consolidated bedrock in weathered shale. None of the wells drilled and completed in December 2020 have sumps.

After PVC screen and casing placement in the borehole, sand filter pack and the bentonite seal were placed via gravity feed from the surface into the annular space. When applicable the sump was sealed in with bentonite to 2-feet below the bottom of the screen. The filter pack consisted of 10-20 (sieve size) washed silica sand emplaced from approximately 2 feet below the bottom of the screen to approximately 0.5 to 2 feet above the well screen. The annular seal of medium bentonite chips was placed above the top of the filter pack and hydrated in lifts throughout placement, while the remaining drill casing was removed from the borehole using the hydraulic jacks.

³ Previously constructed wells W-1, W-2, W-3, and W-4 incorporated a 2-foot sump to capture infiltrating perched water. Due to the lack of a laterally extensive shallow groundwater system in the colluvium deposits beneath the site and the depth of the uppermost aquifer (Dakota Sandstone), a wet/dry monitoring well system is an effective way to detect changes in perched groundwater conditions and/or potential contaminants from the ash landfill and CCR impoundment.

An annular surface seal consisting of neat cement was installed from the top of the bentonite to the surface. All wells were finished with a 2-foot-by-2-foot concrete pad using Quickrete fast setting concrete, extending to a depth of approximately 0.5 to 2 feet below grade (to the top of the bentonite grout). Each well included a PVC stick-up. Each well was secured with a protective steel casing and lock. Well construction is further described in **Section 4.3**.

3.4 Well Development

Wells are typically developed over several days to improve hydraulic connectivity in the area immediately surrounding the well and remove any fluids introduced during drilling. Well development involves removing as much of the introduced drilling fluids, cuttings, and particulates from within and adjacent to the well as possible. Development did not begin until at least 12 hours after the wells had been grouted to ensure grout had sufficiently set.

Wells were to be developed by surge blocking and pumping. This method involves moving a surge block up and down the well screen and casing, which alternately forces water in and out of the screen, loosens sediment, and draws fine-grained materials into the well, then removing the purge water and fine sediment from the well using a pump. Wells MW-5, W-8A, W-10A, and W-13 were found to be dry after installation; therefore, well development was not attempted. Well development at other wells is further discussed in **Section 4.4**.

3.5 Well Survey

Surveying of the monitoring wells was performed by professional surveyor Edward-James Surveying, Inc. after well completion. The surveyor recorded elevations of the top of PVC casing (point at notch on the north side of the casing top) and ground surface using a level loop. The northing and easting coordinates of the wells were initially surveyed using a local coordinate system and converted to NAD 1983 UTM Zone 13 South.

3.6 Groundwater Level Measurement and Aquifer (Slug) Testing

HDR performed slug tests on monitoring wells MW-1B, MW-2B, MW-4B, MW-6, W-2A, W-2B, W-5, W-6, and W-7, to estimate hydraulic conductivity of screened units. Wells that were dry or had water levels that were very slow to equilibrate due to low permeability could not be tested using slug testing methods. All slug tested wells were constructed with 2-in diameter PVC. A 1.5-inch diameter by 2.75-foot long watertight (solid) slug, having an expected initial displacement of 1.53 feet in the wells, was used in all tests. A pressure transducer with integrated datalogger was suspended on a direct-read communications cable near the bottom of each well prior to testing, and water level measurements were recorded at 0.25-second intervals for MW-1B, MW-2B, MW-4B, MW-6, W-2A, W-5, W-6, and W-7, and increasing interval lengths from about 0.4 seconds up to a maximum of about 60 seconds for MW-2B. Both falling head (slug-in, identified as FH) and rising head (slug-out, identified as RH) tests were performed at each well. Slug-in tests were completed by emplacement of the slug into the water column as quickly as possible and measuring the falling water level that followed. Slug-out tests were completed after each slug-in test by removing the slug from the water column as quickly as possible and measuring the rising water level that followed. All non-dedicated down-well equipment used during slug testing was decontaminated after use at each location. Well-specific testing details are summarized below:

MW-1B: Two slug-in and two slug-out tests were performed on October 13, 2020. The static depth to water in the well was 31.20 feet below top of casing (btoc), and the screen was partially submerged with the water table 4.02 feet below the top of the screen interval. The screen length is 15 feet, and the bottom of the screen interval is at a depth of 42.18 feet btoc.

MW-2B: Two slug-in and two slug-out tests were performed on October 12, 2020. The depth to water in the well was 18.30 feet btoc, and the well screen was fully submerged with the top of the screen 4.09 feet below the water table. Screen length is 10 feet, and the bottom of the screen interval is at a depth of 32.39 feet btoc.

MW-4B: One slug-in and one slug-out test was performed on October 13, 2020. The depth to water in the well was 38.42 feet btoc, and the screen was partially submerged with the water table 0.42 feet below the top of the screen interval. Screen length is 20 feet, and the bottom of the screen interval is at a depth of 58.00 feet btoc.

MW-6: One slug-in and one slug-out test was performed on October 13, 2020. The depth to water in the well was 12.95 feet btoc, and the well screen was fully submerged with the top of the screen 16.28 feet below the water table. Screen length is 10 feet, and the bottom of the screen interval is at a depth of 39.23 feet btoc.

W-2A: One slug-in and one slug-out test was performed on October 15, 2020. The depth to water in the well was 27.15 feet btoc, and the screen was partially submerged with the water table 1.94 feet below the top of the screen interval. Screen length is 10 feet, and the bottom of the screen interval is at a depth of 35.21 feet btoc.

W-2B: Two slug-in and three slug-out tests were performed on October 15, 2020. The depth to water in the well was 51.56 feet btoc, and the well screen was fully submerged with the top of the screen 3.64 feet below the water table. Screen length is 20 feet, and the bottom of the screen interval is at a depth of 75.20 feet btoc.

W-5: Two slug-in and two slug-out tests were performed on October 14, 2020. The depth to water in the well was 10.33 feet btoc, and the screen was partially submerged with the water table 2.93 feet below the top of the screen interval. Screen length is 10 feet, and the bottom of the screen interval is at a depth of 17.40 feet btoc.

W-6: One slug-in and one slug-out test was performed on October 14, 2020. The depth to water in the well was 9.65 feet btoc, and the screen was partially submerged with the water table 0.82 feet below the top of the screen interval. Screen length is 10 feet, and the bottom of the screen interval is at a depth of 18.83 feet btoc.

W-7: One slug-in and one slug-out test was performed on October 14, 2020. The depth to water in the well was 6.80 feet btoc, and the well screen was fully submerged with the top of the screen 1.53 feet below the water table. Screen length is 15 feet, and the bottom of the screen interval is at a depth of 23.33 feet btoc.

Slug test data were reviewed real-time during testing and downloaded during and at the end of each working day and saved locally to a laptop computer.

3.7 Decontamination of Field Equipment

Field instrumentation (such as interface probes or water quality meters) was decontaminated between sample locations by rinsing with an Alconox/distilled water solution followed by a potable water rinse and a final rinse with deionized water.

4.0 Field and Laboratory Results

4.1 Borehole Drilling

Boring logs for each borehole are provided in **Appendix A**. Shale was encountered at approximately 14 feet bgs in all three 2015 borings; silt with shale deposits was logged at W-6 while clay with shale was recorded at wells W-4 and W-5 at this depth. This was presumed to be the top of the Pierre Shale formation. A perched, water bearing zone was encountered at 2015 wells W-4 and W-6; W-5 was dry. Approximately 24 hours after drilling, depth to perched water was measured at 14.11 feet bgs at W-4 and 11.10 feet bgs at W-6.

Shale, presumed to be the top of the Pierre Shale formation, was encountered at approximately 24 feet below ground surface at MW-5 and approximately 35 feet at MW-6 during 2017 drilling; therefore drilling was ceased and well screens were placed above the shale. Coarse gravel with sand and a 4-inch layer of brown clay was encountered at this depth at MW-6. Soil cuttings were dry in MW-5. Soil cuttings were dry in MW-6 until moisture was encountered beginning at 20 feet below the surface.

Borings drilled in 2020 consisted primarily of clay, silt, and sand. Shale was encountered at varying depths during both the August and December drilling. In August, shale was encountered at MW-1B at 15 feet below ground, MW-2B at 20 feet, and MW-4B at 56.5 feet. W-2A and W-2B encountered shale at 20 feet below ground, W-7 at 10 feet, and W-8A and W-8B at 22 feet. In December, shale was encountered at W-5B at 29 feet below ground, W-9 at 27 feet, and W-10A and W-10B at 18 feet. To the south of the Comanche Station, shale was encountered at W-11 at 5 feet below ground, W-12 at 18 feet, and W-13 at 23 feet. Most wells transitioned from colluvial silty clay to weathered shale, and then to consolidated shale. Wells MW-4B, W-8A and W-8B, W-9 and W-13 had alluvial sands and gravel interbedded with the colluvium above the shale. Depth to water in January of 2021 was measured at approximately 31 feet below ground surface (bgs) in MW-1B, 16 feet in MW-2B, 8 feet in MW-3, 36 feet in W-4B, 25 feet in MW-5, 30 feet in MW-6, 8 feet in W-1, 26 feet in W-10B, 22 feet in W-11, 20 feet in W-12, 25 feet in W-2A, 10 feet in W-3, 6 feet in W-5, 9 feet in W-5B, 8 feet in W-6, and 6 feet in W-7. Well W-4 collects small quantities of water in the sump below the screen, but the level is not in the screened interval. Dry wells include MW-1, MW-2, MW-4, W-10A, W-13, and W-8A. W-8B was measured at approximately 53 feet bgs, which is accumulation of almost two feet in the well since installation in August 2020 and continues to rise by an inch or two a month but has never stabilized at a static elevation. The well appears to be slowly weeping and therefore is considered functionally dry.

4.2 Soil Samples – Geotechnical Analysis

The undisturbed soil samples collected from the well screen depth intervals of W-4, W-5, and W-6 analyzed for grain size and porosity by HP Geotech are summarized in **Table 1**. The soils laboratory results are presented in **Appendix B**.

Table 1. Summary of Geotechnical Testing Results at Comanche Station, 2015						
Well I.D.	Sample Depth (feet bgs)	Gradation			Porosity (%)	Moisture Content (%)
		Gravel (%)	Sand (%)	Silt and Clay (%)		
W-4	9	0	14	86	36.2	17.2
W-5	9	0	7	93	39.2	18.9
W-6	9	0	8	92	35.4	17.4

Note:
BGS = below ground surface

Laboratory results show the wells are screened in silt and clay with some sand, with porosities between 35 and 40 percent, which is consistent with the silt and clay colluvial material noted in the drilling logs. A general range of hydraulic conductivity for such sediments is 10^{-9} to 10^{-4} centimeter per second (cm/s) (Fetter, 1994).

Samples were taken from all 2020 installed wells except W-2A and W-8B. The geotechnical laboratory results are summarized in **Table 2**. Advanced Terra Testing results are included in **Appendix B**.

Table 2. Summary of Geotechnical Testing Results at Comanche Station, 2020				
Well I.D.	Sample Depth (feet bgs)	Lithology	Permeability (cm/s)	Moisture Content (%)
MW-1B	8-8.5	Clay	8.51E-09	19.0
	28-30	Highly weathered shale	6.62E-08	20.0
MW-2B	4-5	Clay	5.25E-08	25.3
	20-21	Highly weathered shale and fractured	1.03E-08	17.0
	68-78	Shale, unweathered unfractured	5.28E-10	5.6
MW-4B	14-15	Sand with gravel (alluvial)	No cohesion	2.1
	37-39	Clay	3.68E-09	24
	89-90	Shale, unweathered unfractured	1.14E-08	5.0
W-2B	6-7	Silty clay	2.09E-05	24.4
	10-11	Clay	5.93E-09	13.7
	28-29	Slightly weathered shale, iron oxide staining	1.90E-09	10.5
W-7	64-65	Shale, unweathered unfractured	1.36E-08	5.7
	11-12	Highly weathered shale and fractured	5.04E-09	18.5
W-8A	4-5	Silty clay with sand and gravel	2.57E-07	19.2
	9-10	Silt with fine sand	6.66E-05	28.1
	17-18	Well graded sand with gravel (alluvial)	5.10E-03	12.6
	43-44	Shale, unweathered unfractured	1.54E-09	6.1

Note:
BGS = below ground surface

4.3 Well Construction

Approximately 10 feet of screen was installed in each well in 2015 and 2017. The screen was placed above the Pierre Shale formation from approximately 3.4 to 13.4 feet bgs at W-4, 3.5 to 13.5 feet bgs at W-5, 5 to 15 feet bgs at W-6, 16 to 26 feet bgs at MW-5, and 27 to 37 feet bgs at MW-6. The 10-foot blank casing sumps were placed below each well screen in 2015 and 2017; except at MW-6 a 5-foot blank casing sump was placed below the well screen. Total well depths (including the sumps) ranged from 23.4 to 42 feet bgs. A diagram for wells drilled in 2015 and 2017 that documents well construction is provided in **Appendix C**.

Wells installed in August 2020 were installed with well screens of 10 to 20 feet. The screen was placed from 25 to 40 feet bgs at MW-1B, 20 to 30 feet bgs at MW-2B, 38-58 feet bgs at MW-4B, 24 to 34 feet bgs at W-2A, 53 to 73 feet bgs at W-2B, 6 to 21 feet bgs at W-7, 15 to 30 feet bgs at W-8A, and 35 to 55 feet bgs at W-8B. Wells installed in August 2020 do not include blank sumps; the screens extend to the bottom of the wells. Total well depths ranged from 21 to 73 feet bgs.

Wells installed in December 2020 were installed with well screens of 5 or 10 feet and no blank casing sumps. The screen was placed in weathered shale above the consolidated bedrock from approximately 30.5 to 35.5 feet at W-5B, 27.35 to 37.35 feet at W-9, 7 to 17 feet at W-10A, 20 to 30 feet at W-10B, 23 to 33 feet at W-11, 14 to 24 feet at W-12, and 245 to 29 feet at W-13. Total well depths ranged from 18 to 40 feet bgs. A diagram for wells drilled in 2020 that documents well construction is included on the boring logs in **Appendix A**.

Well construction details for all 20 wells are summarized in **Table 3**. State-issued well construction permits are included in **Appendix D**, where available.

Table 3. Well Construction Details for Installed Groundwater Monitoring Wells

Well ID	Easting (State Plane, NAD 1983 UTM Zone 13 S meters)	Northing (State Plane, NAD 1983 UTM Zone 13 S meters)	Elevation TOC (feet AMSL)	Well Total Depth (feet bgs)	Depth of Screen Interval (feet bgs)	Well Stickup (feet)	Casing Type	Depth to Water (feet BTOC) Jan. 6 2021	Static Water Level (feet AMSL) Jan. 6 2021
W-4	537310.48	4228491.35	4812.47	23.4	3.4-13.4	3.63	2-inch PVC	26.59	4785.88*
W-5	537396.38	4228323.54	4807.46	23.5	3.5-13.5	3.83	2-inch PVC	8.07	4799.39
W-6	537367.35	4228447.92	4811.89	24.54	5-15	3.90	2-inch PVC	9.67	4802.22
MW-5	536379.92	4228619.73	4806.97	36.0	16-26	2.43	2-inch PVC	27.19	4779.78
MW-6	536363.95	4228008.02	4823.08	42.0	27-37	2.23	2-inch PVC	31.60	4791.48
MW-1B	536729.52	4228051.34	4807.72	40.0	25-40	2.18	2-inch PVC	31.23	4776.49
MW-2B	536776.74	4228351.21	4801.72	30.0	20-30	2.39	2-inch PVC	18.32	4783.40
MW-4B	535974.97	4228278.78	4826.41	58.0	38-58	2.31	2-inch PVC	38.35	4788.06
W-2A	537556.62	4228795.47	4827.86	33.0	23-33	2.21	2-inch PVC	27.07	4800.73
W-2B	537556.64	4228794.12	4827.80	73.0	53-73	2.20	2-inch PVC	52.26	4775.60
W-7	537560.80	4228271.43	4797.80	21.0	6-21	2.33	2-inch PVC	7.74	4790.06
W-8A	537487.53	4227922.80	4804.26	30.0	15-30	2.16	2-inch PVC	Dry	Dry
W-8B	537488.42	4227922.79	4804.46	55.0	35-55	2.33	2-inch PVC	55.36	4749.10*
W-5B	536380	4228325	4810.62	36.0	30.5-35.5	2.50	2-inch PVC	11.31	4810.14
W-9	537562	4228088	4801.78	40.0	27.35-37.35	2.31	2-inch PVC	36.50	4765.28
W-10A	537490	4228951	4835.21	18.0	7-17	2.22	2-inch PVC	Dry	Dry
W-10B	537490	4228953	4835.22	31.0	20-30	2.21	2-inch PVC	28.03	4807.19



W-11	536898	4227888	4895.99	34.0	23-33	2.38	2-inch PVC	23.61	4772.38
W-12	537107	4227869	4791.65	25.0	14-24	2.22	2-inch PVC	21.93	4769.72
W-13	537292	4227853	4801.96	29.0	24-29	2.30	2-inch PVC	Dry	Dry

Notes:

TOC = top of casing

BTOC = below top of casing

BGS = below ground surface

*Water level measured Jan 6, 2021 but not static water level. Water building up in the sump in W-4, and water slowly seeping into the screen in W-8B rather than a static level. W-8B assumed to be functionally dry.

4.4 Well Development

On November 11, 2015, the depth to water was measured in each 2015 installed well in preparation to begin well development. Well W-5 was found to be dry; therefore, well development was not attempted in this monitoring well. Well development was not attempted at well W-4 due to the lack of water in the screened interval. Well development was attempted at well W-6 but was ultimately unsuccessful due to extremely slow recharge in the well, combined with a water level of only 3 feet within the wetted screened interval (above the sump).

On August 8, 2017, the depth to water was measured at MW-6 in preparation to begin well development on MW-6. Well development continued on August 9 and 10; approximately 315 total gallons of water was purged during the development of MW-6. Well development was not attempted at MW-5 due to the lack of water in the screened interval.

On August 19, 2020, the depth to water was measured at W-2A, W-2B, and W-7 prior to beginning well development on 2020 installed wells. Well development continued through August 21 for W-7; approximately 500 liters of water was purged. Well development of W-2A and W-2B continued through August 25; approximately 94 liters was purged from W-2A and 48.5 liters from W-2B. On August 20, 2020, depth to water was measured at MW-1B, MW-2B, MW-4B, and W-8B prior to development. Development of MW-1B continued through August 21 with a total of 311 liters purged. Development of MW-2B continued through August 24 with a total of 697.5 liters purged. Development of MW-4B continued through August 25 with a total of 313 liters purged. Development of W-8B continued through August 27 with a total of 11 liters purged. Well W-8A was dry.

On December 16, 2020, the depth to water was measured at W-9 prior to beginning well development. Well development continued December 17, 18, 22, 23, 28, 29, January 4, 5 and 6; approximately 230 liters of water was purged. Development of wells W-10B, W-11 and W-12 began on December 17, 2020, after preliminary static water level measurements. Approximately 67.5 liters of water was purged from W-10B through January 6, 2021. Well development of W-11 and W-12 continued through December 21, 2020; approximately 420 liters of water was purged from W-11 and 136 liters from W-12. On December 22, 2020, depth to water was measured at W-5B before approximately 481 liters of water was purged and development was completed.

4.5 Well Survey

Survey coordinates and elevations are provided in **Table 3**.

4.6 Groundwater Level Measurement and Aquifer (Slug) Testing

All slug-in and slug-out tests were analyzed using AQTESOLV® v4.5 (<http://www.aqtesolv.com>), with the Bouwer and Rice (1976) or KGS Model (Hyder et al. 1994) solutions for wells with the water table in the screened interval, and the Hvorslev (1951) or KGS Model solutions for wells with the screen intervals fully submerged. Solutions for unconfined and confined conditions were applied based on the water level position, and logged lithology at and above the screened interval. Unconfined conditions solutions were applied consistently to wells with the water table across the screen. Confined conditions were assumed for wells MW-2B and W-5.

Nominal casing diameter was assumed to be 2 inches for all wells. Well bore diameter was set equal to either 5 inches or 8 inches depending on the drill bit size used to drill the entirety or majority of the

screened intervals. No well skin beyond the radius of the well bore was assumed. For wells with screens below the water table (i.e. fully submerged) during the slug testing, no effective casing radius correction was applied. For wells screened across the water table during slug testing, the Bouwer-Rice method (Bouwer and Rice 1976) of correcting the casing radius for the effective porosity of the filter pack was applied to account for drainage to and from the filter pack. The effective porosity of the filter pack was assumed equal to 30%, considering that it should approximately equal the specific yield of the material (10-20 silica sand), and specific yield for sand varies between 30% and 33% based on Morris and Johnson (1967). The saturated aquifer thickness at each location was represented using the saturated screen length and included portions of aquifer above the well screen where submerged and the logged lithology indicated presence of aquifer materials. An anisotropy ratio for hydraulic conductivity (ratio of horizontal to vertical hydraulic conductivity) of 1 (unitless) was assigned to the aquifer at each well location; routine sensitivity checks on this parameter indicated little to no sensitivity.

Data identified as “noisy” due to non-instantaneous response at the initiation of the tests, were plotted and reviewed but not fitted during the analyses, following the translation method recommended by Butler (2020). Comparison of normalized displacement data and resulting hydraulic conductivity values for some tests were judged to be of low reliability and non-representative, therefore these tests were excluded from further consideration and other test results were retained. The tests excluded in this way include W-5 test FH2, and W-2B tests except for test RH3.

4.6.1 Results

Initial displacement caused by emplacement or removal of the solid slug in the wells and hydraulic conductivity results for the slug testing are shown in **Table 4**. In some tests the initial displacement did not reasonably match the expected displacement of 1.53 feet. For some tests the KGS Model solution results are presented in addition to the straight-line solutions (W-2A and W-7 slug out or Rising Head) in **Table 4**. Plots of slug test analyses are included in **Appendix E**. The range of the hydraulic conductivity calculated values were from a low of 1.9×10^{-7} centimeters per second (cm/sec) to a high of 8.3×10^{-3} cm/sec, generally corresponds with the textbook ranges (Freeze and Cherry 1979) for the shale bedrock, fat clay and lean clay on the low end, and weathered and fractured shale bedrock, silt and silty sand to sand on the high end, as described on the field boring logs. **Table 5** provides the geometric mean hydraulic conductivity values for wells that were pooled together based on the primary lithology of the well screen interval.

Table 4. Slug Testing Results

Well	Screened Interval Lithology	Test Name	Analytical Solution	Initial Displacement (feet)	Hydraulic Conductivity (cm/sec)	Hydraulic Conductivity Geometric Mean (cm/sec)
MW-1B	Highly weathered and slightly weathered shale	Falling Head (Slug In) 1	Bouwer-Rice	0.905	2.8E-05	2.0E-05
		Falling Head (Slug In) 2	Bouwer-Rice	0.837	1.3E-05	
		Rising Head (Slug Out) 1	Bouwer-Rice	0.584	4.2E-05	
		Rising Head (Slug Out) 2	Bouwer-Rice	0.687	1.1E-05	
MW-2B	Highly weathered and unweathered, fractured shale	Falling Head (Slug In) 1	KGS Model	0.106	7.1E-03	4.6E-03
		Falling Head (Slug In) 2	KGS Model	0.131	1.1E-03	
		Rising Head (Slug Out) 1	KGS Model	0.626	8.3E-03	
		Rising Head (Slug Out) 2	KGS Model	0.509	6.7E-03	
MW-4B	18.5' Colluvium (clay), 1.5' highly weathered shale	Falling Head (Slug In) 1	KGS Model	1.156	1.1E-05	1.2E-05
		Rising Head (Slug Out) 1	KGS Model	1.119	1.4E-05	
MW-6	8' Colluvium (clay and silt and gravel), 2' highly weathered shale	Falling Head (Slug In) 1	Hvorslev	1.356	7.0E-04	1.1E-03
		Rising Head (Slug Out) 1	Hvorslev	1.401	1.8E-03	
W-2A	Highly weathered and slightly weathered shale	Falling Head (Slug In) 1	Bouwer-Rice	1.113	9.7E-05	1.0E-04
		Rising Head (Slug Out) 1	Bouwer-Rice	1.561	1.8E-04	
		Rising Head (Slug Out) 1	KGS Model	1.561	5.9E-05	
W-2B	Unfractured, unweathered shale	Rising Head (Slug Out)	KGS Model	1.481	1.9E-07	--
W-5	Colluvium (clay with sand and gravel)	Falling Head (Slug In) 1	Bouwer-Rice	1.111	2.1E-06	2.4E-06
		Rising Head (Slug Out) 1	Bouwer-Rice	1.314	2.1E-06	
		Rising Head (Slug Out) 2	Bouwer-Rice	1.388	3.3E-06	
W-6	Colluvium (clay and silt with sand)	Falling Head (Slug In) 1	Bouwer-Rice	0.423	8.0E-05	8.0E-05
		Rising Head (Slug Out) 1	Bouwer-Rice	0.623	8.1E-05	
W-7	4' Clay, 11' highly weathered shale	Falling Head (Slug In) 1	Hvorslev	0.523	3.0E-04	4.3E-04
		Rising Head (Slug Out) 1	Hvorslev	0.802	8.3E-04	
		Rising Head (Slug Out) 1	KGS Model	0.802	3.3E-04	



Table 5. Hydraulic conductivity by lithologic unit

Wells with Similar Screen Lithology	Screened Interval Lithology	Hydraulic Conductivity Geometric Mean (cm/sec)
W-1B, MW-2B, W-2A, W-7	Weathered shale	2.52E-04
MW-2B	Unfractured, unweathered shale	1.90E-07
MW-4B, MW-6, W-5, W-6	Colluvium	4.07E-05

5.0 References

- Bouwer, H. and R.C. Rice, 1976. A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, *Water Resources Research*, vol. 12, no. 3, pp. 423-428.
- Dagan, G., 1978. A note on packer, slug, and recovery tests in unconfined aquifers, *Water Resources Research*, vol. 14, no. 5. pp. 929-934.
- Freeze, R.A. and J.A. Cherry, 1979. *Groundwater*, Prentice-Hall, Inc., Englewood Cliffs, NJ.
- GeoTrans, Inc. (2009). Surface Water Impoundment Infiltration Characterization Analysis, Public Service Company of Colorado, Comanche Station, Pueblo, Colorado, December 1, 2009.
- HDR, 2015a. Monitoring Well Installation Plan for Compliance with the Coal Combustion Residuals (CCR) Rule, Comanche Station. Xcel Energy.
- HDR, 2015b. Groundwater Monitoring System Certification for Compliance with the Coal Combustion Residuals (CCR) Rule, Comanche Station. Xcel Energy.
- Tetra Tech, 2012. Inventory and Preliminary Classification Report, Waste Impoundments, Comanche Station, Pueblo, Colorado, November 1, 2012.
- Tetra Tech, 2014. Sitewide Monitoring Plan, Ash Disposal Facility, Comanche Station, Pueblo, Colorado, August 29, 2014.
- Tetra Tech, 2015. Engineering Design and Operations Plan, Ash Disposal Facility, Comanche Station, Pueblo, Colorado, January 13, 2015.
- URS, 2005. Geotechnical Investigation, Unit 3, Comanche Station, Pueblo, Colorado, March 2, 2005.
- Woodward-Clyde Consultants, 1987. Feasibility Investigation, Two Ash Disposal Areas for Comanche Power Station, Pueblo, Colorado. March 1987.
- Xcel Energy, 2005. Comanche Station Coal Ash Disposal Facility Design and Operations Plan. August 24, 2005.